INFRARED SCENE GENERATION, PROJECTION, AND BLENDING WITH RADIO FREQUENCY ENERGIES FOR HARDWARE-IN-THE-LOOP SIMULATION TESTING

by

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ABSTRACT

As missile systems are becoming more complex and the costs associated with live-fire testing are continuing to grow, greater emphasis is being placed on thorough system testing and capability evaluation in the simulation laboratories. To fully test these advanced missile guidance systems the simulation test facilities must present realistic, in-band, backgrounds, targets, and countermeasures to the systems being tested. This paper describes an ongoing tri-service developmental program, Multi-Spectral Scene Generation (MSSG). MSSG includes the generation and projection of complex infrared scenes in a real-time closed-loop sense for testing in hardware-in-the-loop simulation test facilities. The combination of RF and IR energies for the presentation to the seeker/guidance system for simultaneous RF/IR testing is also part of this project. The scene generation must accommodate a 512x512 array of thermal pixels at a repetition rate of one-hundred Hertz. The infrared scene will be generated with 12 bits of resolution over the temperature and/or emittance values. The interface between the scene generator and the infrared scene projector must transfer and receive this "big-gulp" of data and pass it on to the seeker/guidance system without creating data artifacts. All projection system non-uniformity's must be removed and the system must be kept in calibration during the testing process. The beam combiner must pass the RF radiation with minimal effect on the amplitude and phase, and must also reflect the IR radiation with minimal effect on the intensity and angular position of the test signals. The generation, projection, and blending of the IR and the RF signals must be accomplished without corrupting either signal to the point where data artifacts are created by the test process or the test facility.

INTRODUCTION

The dual purpose of this paper is to introduce you to the wide range of missile test options available and to focus your attention on the advanced test capabilities currently being developed for hardware-in-the-loop (HWIL) simulation testing of infrared (IR) and combined infrared-radio frequency (IR/RF) guided missile systems. The three services have been working to improve the test capability of HWIL simulation test facilities to match the growing capability in missile seeker and guidance sections. The Central Test & Evaluation Investment Program (CTEIP) is currently funding a tri-service project to bring this service expertise together to complete the development and installation of combined radio frequency and infrared scene projection for testing missile seekers in HWIL simulation test facilities for each of the three services.

Although the advances in missile guidance units have improved missile capability to acquire, track, and intercept targets, this two edged gain in capability also requires far more extensive testing to thoroughly evaluate this improved system capability. This demand for greater testing comes at a time when field test assets are becoming more scarce, tests costs are escalating, and environmental concerns are adding additional time and money burdens. As a result, the testing emphasis is necessarily shifting away from field testing to a more broadly based test program that includes extensive simulation and laboratory testing. This

shift includes the requirement to ensure validity in the simulation testing process.

There is at least one major risk associated with this process. If, for example, a program should decide they are going to put their available resources into developing a single simulation test technique to supplement their limited field testing, the use of this single simulation test technique may bias the evaluation results because of the inadvertent introduction of test-technique-specific data artifacts. It is important that programs utilize a balanced mix of test methods with comparative checks and balances among the techniques to avoid this.

TESTING TECHNIQUES

Misleading data from a limited scope evaluation process might be the basis for developmental decisions that could cost huge amounts of time and money, or even lead to the cancellation of the program. Even worse, if a defective missile system somehow makes it into operational use, the results could very well be catastrophic on the battlefield.

A better approach in the system evaluation process is to direct that the testing be done using several complementary techniques and these testing techniques are designed so the results from each are directly comparable, that these results are compared, and action taken.

Each testing technique has its own suite of strengths and weaknesses. For example, digital simulations are best used to do the predictive analytical studies to help define system requirements before the design process is initiated and hardware has become available. As the design comes together and major components of the system are being tested through laboratory bench testing, this new information should be inserted in the digital simulation and the analyses re-run for confirmation or re-direction of the design. As the missile seekers become available they should be tested for acquisition sensitivity and tracking on such laboratory instruments as the rate tables that are being used for infrared seeker testing. When the seekers and their signal processing electronics are mated to the guidance systems, the digital six degree-of-freedom (dof) fly-out models should be used to close the loop around the missile seeker/guidance system in HWIL testing. (Six dof refers to the three spatial coordinates of the target, the three directional vectors relating the missile guidance system to the pursued target, and the fly-out capability of the target and the missile airframe.)

These initial HWIL tests ought to be designed so the results can be directly compared with those results obtained from the upgraded digital models. If paradoxical differences arise from these direct comparisons, these must be addressed, fully understood, and fixed before going on. At times the conclusion will be that further data is needed, perhaps from fly-over or captive carry testing, before the paradoxical results can be dealt with. This kind of an approach will raise the probability of completing a successful developmental program, especially considering the complexity of today's missiles, from near zero to nearly one.

Assuming that the analytic techniques can be made to agree and that the analytical results compare well with the results from the captive carry and fly-over testing, the next step is to commit the hardware to live-fire testing. Use of the digital simulations and HWIL simulation testing (using the actual flight hardware) to predict the live-fire test results is a required part of this testing process so the predictive results can be directly compared with the results of the live-fire testing. If conflicting results arise from this testing, or flight failures occur, it is important that the reasons be found, completely understood and fixed before continuing the program.

Using such an analyze, test, analyze, and fix procedure maximizes the probability that any data artifacts introduced by poorly designed tests,

incomplete test techniques, and flawed test equipment will be discovered and removed from either the test process or the missile hardware and software, or both.

When the evolutionary process of the analysis, hardware testing, and field testing is done correctly, the required Verification, Validation, & Accreditation process required to support the digital and HWIL simulation test models will flow out of the developmental system naturally.

Table One presents a spectra of test techniques that are available for missile program testing. The applicability rating for these techniques is general and is not always indicative of the correct approach for the individual programs. It is presented as an aid to the program manager for a stepping off place for the design of your test process. (That is--this is not an unalterable piece of infallible testing guidance.)

Table One: Test Techniques and Applicability

Test Technique	Best Use
Digital Simulation	D
Bench Test	D/C
Rate Table	D/C
Hardware-in-the-Loop	D/C/S
Fly-By	C/S
Captive Carry	C/S
Aircraft System	S
Live-Fire	S

D--Requirements/Design Phase
C--Component Testing
S--System Testing

When cost, asset availability, and test repeatability are issues, HWIL simulation testing may be the best tool to use for design evaluation and for the analyze, test, analyze, and fix process.

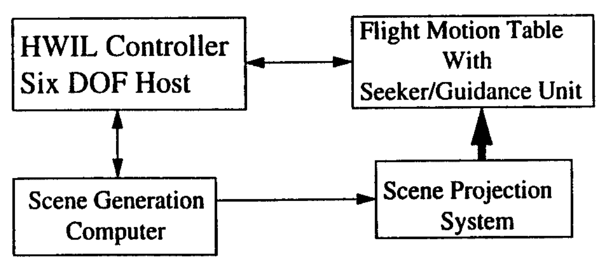
VERIFICATION, VALIDATION, AND ACCREDITATION

This is one of the few chances I'll have to lay my simplistic definitions on you, so here goes: Verification means we have determined that the digital and HWIL simulation test systems are doing what we think they're doing. Validation means that we have determined that the missile test results from the digital and the HWIL simulation testing match the missile test results from the captive carry, fly-over, and live-fire field testing. Accreditation means that the independent tester of the fully developed missile system is convinced that the digital and HWIL simulation test capability developed through the developmental process associated with the program has been verified, validated, is under change control, and that this independent tester is willing to sign up to this fact.

HARDWARE-IN-THE-LOOP

To understand the importance of target, background, and countermeasures projection in the HWIL simulation testing process, it's necessary to understand the rudiments of the hardware-in-the-loop simulation testing process. Figure One shows the major components of the HWIL system.

Figure One: Block Diagram Showing Major Hardware-in-the-Loop Components



The most important difference between HWIL simulation testing and other forms of simulation testing is the actual use and testing of flight-capable seeker and guidance hardware in HWIL simulation testing. All other forms of simulation testing, such as signal injection and digital, bypass some or all of the missile seeker and/or guidance hardware. The use of actual flight hardware in the simulation testing

means that the results are, by definition, closer to those expected from the live-fire flight testing.

The flight motion simulator holds and moves the missile hardware to be tested in flight-like motions during the simulated flight scenarios. Pitch, yaw, and roll motions of the three degree of motion flight motion tables simulate the motion of the missile guidance unit in flight. The additional two axes associated with a five axis flight motion table would hold and move the target projection system in azimuth and elevation.

The acceleration, velocity, and position capability of the flight motion tables vary significantly from system to system. Tables Two and Three contain such information for the "old" IR 1 flight motion table in the Missile Simulation Laboratory (SIMLAB) at the Naval Air Warfare Center Weapons Division at China Lake, California, and the "new" IR 1 five axis flight motion table currently being fabricated by Carco Electronics, Inc. for installation in the SIMLAB in March of 1997. In particular, you may note that the position limits associated with the new flight motion table cover a much larger span with higher accelerations and higher rates than those of the "old" IR 1 flight motion table. (Old IR 1 was used to do the bulk of the Sidewinder HWIL testing at China Lake.)

Table Two: "Old" IR 1 Flight Motion Table Capability

Missile--	Yaw	Pitch	Roll
Displacement (± deg)	120	120	cont.
Max. rate (deg/sec)	400	200	1800
Bandwidth (Hertz)	13	13	28

Table Three: "New" IR 1 Flight Motion Table Capability

Missile--	Yaw	Pitch	Roll
Displacement (± deg)	45	120	cont.
Max. Rate (deg/sec)	400	400	7,200
Max. Accel. (deg/sec^2)	9K	13K	17K
Bandwidth (Hertz)	20	20	25

Target/Scene--	Azimuth	Elevation
Displacement (± deg)	120	45
Max. Rate (deg/sec)	200	200
Max. Accel. (deg/sec^2)	1,200	1,000
Bandwidth (Hertz)	7.5	6.5

The fourth and fifth axes that carry the target/scene projection system do not have the same stringent requirements for rapid movement as do the missile seeker/guidance section axes.

The control computer hosts the six dof digital model and drives the targeting system and the flight motion table to the correct positions, rates, and accelerations throughout the chosen flight test scenario. This system generally outputs the scenario flight test results in terms of closest point of approach between the missile system and its target.

Closing the loop around the seeker/guidance system is the major driver of the performance requirements laid on all HWIL systems. If the missile guidance system commands a three gee turn to the left, for example, that information goes to the control computer which computes and sends correlated commands to the flight motion table and the infrared target/scene projection system. As the control computer processes the missile flight and compares the spatial position of the missile with that of the target, the character of the target, background, and countermeasures will be required to change from the missile's perspective. This information must be computed on the fly and must be translated into control commands to run the flight scenario through intercept, that is, pre-scripted scenarios are not flown in the HWIL system during evaluation testing.

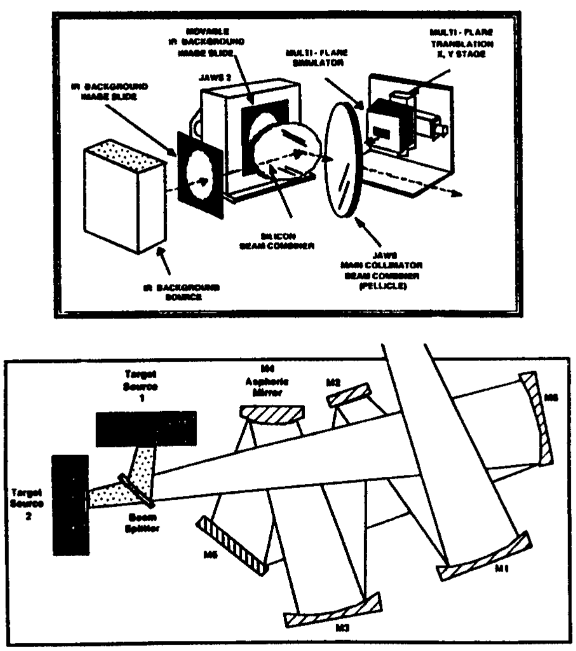
As the requirements for complexity in the evaluation process grow, the time required to compute increases. The retention of timeliness in the data flow and the resulting motion of the flight motion table, and especially in the

output from the scene projection system becomes a critical factor.

Infrared target projection systems have historically been limited to the projection of simple point source type targets. The growing complexity of missile systems and the need for lock-on-after-launch is forcing testers to improve their testing capability.

The addition of static backgrounds, moving multiple targets, and dynamic countermeasures represents the initial development of such improved testing capability. Figure Two shows an artist's concept of the existing JAWS II infrared scene projection optics bench in IR 2 in the SIMLAB at China Lake. This reflective optics bench projects infrared scenes in both the 3 to 5 and 8 to 12 micron energy bands (mid and long wave band) to the missile system being tested.

Figure Two: JAWS II Infrared Scene Projection Optics Bench in IR 2

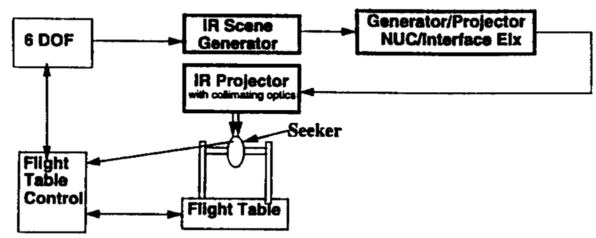


The upper drawing shows the blending of targets, countermeasures and a static background scene. The lower drawing shows the optical system. The JAWS is capable of projecting scene information over a twelve degree, twelve inch field at 0.2 to 0.3 milliradian physical resolution.

While IR 2 represents a giant step forward in infrared scene projection for missile testing, more advanced missile systems and the shrinking field test budgets are demanding more in the way of dynamic test capability from this aspect of hwil simulation testing.

Figure Three shows a block diagram illustrating the dynamic infrared scene projection system to be mounted on the fourth axis of the "new" IR 1. Refractive optics designed for operation in the 3 to 5 micron band are being used here because of the limited volume and capacity for weight handling (300 pound limit) on the fourth axis of the five axis table.

Figure Three: Five Axis Dynamic Infrared Scene Projector Block Diagram



This dynamic infrared scene projection system will be using a 512 pixel by 512 pixel array of micro-miniature resistors to provided the scene energy to be projected to the seeker-guidance system being tested. The scenes being projected by this system are on continuously to avoid projector scan/seeker scan interference and artifact creation. Although these resistors are continuously on, the voltage and current levels driving the heater are being updated at a one-hundred Hertz rate. The generation and transfer of the information required to drive this array of resistors will be done by the Silicon Graphics Infinite Reality Engine 2. The resistors in the arrays are not entirely uniform as manufactured, so the resistors are individually calibrated and compensated for non-uniformity (NUC), as voltage offsets and variable gains in current gain. These

become part of the interface electronics that feeds the resistor array drive electronics. This scene, after entering the array drive electronics, is emitted from the resistor array, passes through the collimating optics, and impinges on the seeker.

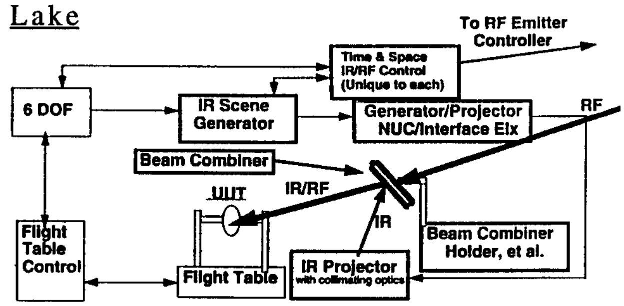
And, as noted, the closed loop operation of this system imposes stringent speed requirements on the capability of the dynamic scene projection system. This closed-loop speed requirement grows each time dynamic range, physical resolution, temperature resolution, total projected field of view, and the like, grow. The allowable data latency in a closed-loop hwil test system depends on the character of the system being tested; responsivity, signal processing latency, missile time constant, seeker scan rates, et al. The typical scene latency being specified for infrared projection systems is no more than three frames (with one-and-one-half frames being desireable. At a one hundred Hertz update rate, the maximum specified delay is three hundredths of a second. Typical fast missile time constants are one-tenth of a second. If there is a three cycle processing delay in the missile signal processor between signal input in and control commands out, the closed loop update rate delay becomes insignificant. Even if the signal processing delay is zero, the projector frame latency should cause no measurable degradation in the quality of the missile capability evaluation.)

The five axis system will be the first of the dynamic infrared scene projection systems to be brought on line at China Lake. The initial operation is scheduled for March of 1997.

MULTISPECTRAL SCENE GENERATION

Beyond the ongoing and planned improvements for the infrared dynamic scene projection systems, testing of advanced systems will require the co-temporal and co-spatial presentation of multi-spectral scenes/energies in more than one of the following spectral areas: infrared, ultraviolet, visible, radar, and millimeter wave bands. Figure Four shows an artist's concept of the NAWCWD China Lake RF 3 facility that is under development as part of the tri-service developed, CTEIP funded Multi-Spectral Scene Generation (MSSG) project.

Figure Four: Multi-Spectral Scene Generation Installation in RF 3 at China Lake



It has long been the goal of the hwil infrared missile seeker test community to provide dynamic infrared scenes to the seekers being tested. Historically, we've had to settle for single point source targets and single point source countermeasures. More recently we've been able to add fixed infrared backgrounds, multiple targets, and multiple countermeasures. Within the recent past there has been a major break-through in the area of large field-of-view, high resolution resistor array driven infrared scene projection systems with good dynamic range and excellent speed. These arrays do very well in the long wave band but do not, and may never, have the upper-end temperature range to meet the requirements of the hotter items in the 3 to 5 micron band. Nevertheless, this is the first technology to crack the dynamic scene projection barrier with a system that can be used for advanced testing in the infrared band. The simultaneous requirement for high dynamic temperature range and high speed has caused more than one proposed scheme to flounder on the requirements shoals.

The resistor arrays require (as do all infrared sources) calibration and they also require non uniformity compensation (nuc) of the less than

perfectly uniform arrays. This compensation usually takes the form of a voltage offset and a variable gain curve (e.g. picowatts per cm^2/ amp) for each of the emitters. In a 512x512 pixel array there are more than 260,000 resistors, so remembering the nuc for each requires a non trivial memory.

The arrays themselves are expensive, at about $250K apiece, although most of the hardware in infrared projection systems falls under the category of non recurring cost items so the active element (resistor array) can be replaced whenever something better and/or cheaper comes along.

In the CTEIP funded MSSG project to blend the RF and IR energies, it was decided to reflect the IR energies and transmit the RF energies mainly because the participants had radio frequency chambers that could be modified to accept the infrared projection systems and because materials were found that would handle the RF transmission requirements and the IR reflection requirements with minimal distortion.

Anytime additional hardware elements are introduced in test chambers, some signal distortion will take place. The guidelines being used for this project allow signal distortion so long as it does not exceed one-third of the inherent resolution of the seekers being tested.

Although the beam combiner remains as one of the key developmental challenges, along with the higher temperature resistor arrays, and the high speed demands of closed loop scene generation, none of these elements are excessively risky and will meet our immediate testing needs when completed.

REQUIREMENTS

The Navy Rolling Airframe Missile (RAM) requires moving 3 to 5 micron infrared scenes and moving X band RF energy sources. The facility that provides this projection & blending capability is quite different from the Army's need for testing the Brilliant Anti-Tank weapon (BAT). The BAT requires both the 3 to 5 micron and the 8 to 12 micron band infrared energy scenes and millimeter wave band RF energy. Synthetic line of sight techniques will be used for the BAT so the IR and RF scenes do not need to move physically.

The Air Force has chosen to correlate 8 to 12 micron infrared sources with X band RF energies while using synthetic line of sight techniques to avoid having to move the projected scenes in their test facility.

OTHER PROJECTS

The development community that is working toward the creation and improvement of dynamic infrared scene projection systems is small so we know everyone who's working in the business. Some may call our interactions synergistic, others name it incestuous. However it's labeled, the individual requirements among the testers vary greatly. The projection systems that are developed for the missile testers won't work for the folks who want to test Forward Looking Infrared (FLIR) systems and vice versa. The FLIR folks need 8 to 12 micron IR energy scenes, high resolution in temperature and space, and large areas of background with embedded targets. The missile folks need 3 to 5 micron hot targets in moderate backgrounds with the option for lots of hot flailing countermeasure type things. And the systems that will test the air-to-air missile seekers won't work well for the air-to-mud folks for many of the same reasons.

The development of flexible infrared scene projection systems blended with the RF energies in frequencies ranging up into the MMW are doable and will be coming along as the baseline systems come on line and have the bugs worked out. But none of these systems will arrive bursting with the exuberance of teenagism and the experience of the golden years wrapped up in tight little packages. But arrive, they will. By December of 1997, three

dynamic infrared projection systems will be actively and effectively testing missile seekers in the Army, Navy, and Air Force. By the year 2000, dynamic RF/IR projection systems will be actively involved in missile testing in the three services. Possibly aircraft system testing will be coming on line in the Air Force and Navy giant anechoic test chambers by then as well.

Table Four: Organizations

Defense Nuclear Agency--Low Temperature Needs (DNA has been actively involved in the development of resistor arrays for infrared scene projection from the beginning. Their systems are being used by the Arnold Engineering Development Center in Tullahoma, Tennessee)

Honeywell--Resistor Array Manufacturing (Honeywell is one of three manufacturers that is designing and fabricating resistor arrays for infrared scene projection. Currently, they are the most advanced of any of the manufacturers.)

Optical Etc.--Small Resistor Array Manufacturing (Optical Etc. is being sponsored by Navy Research and Development in San Diego and funded by Office of Naval Research (ONR) to design and fabricate smaller resistor arrays to be used in missile test sets. This project is emphasizing the inexpensive aspects of resistor array development. Future cost reduction in this area may depend heavily on this work. Optical Etc. also does the full system design, fabrication, and test.)

Mission Research Corp.--Infrared projection system design, fabrication, and test using the resistor array as the foundation stone on which to build. They were the ones who worked with Honeywell and the Defense Nuclear Agency to develop the Honeywell resistor array of emitters.

British Aerospace--Resistor Array Manufacturing (The British are developing resistor arrays for the testing of infrared missiles in England.)

Edwards AFB--SBIRs and Anechoic Facility Testing (Edwards AFB is supporting a number of phase 1 & 2 Small Business Innovative Research projects to support the generation of and the projection of infrared scenes.)

NAWCAD, Patuxent River--Anechoic Facility Testing, Data Base Acquisition (Pax is leading the joint (Edwards) development of infrared scene generators for introduction of infrared scenes into the aircraft systems in the aircraft anechoic facilities in the Air Force and the Navy.)

MICOM, Redstone Arsenal--Missile Seeker Testing, Advanced Scene Generation, Laser Array Scene Projection (MICOM is one of the active participants in the MSSG project and is leading the scene generation part of that project.)

Wright Laboratory, Eglin AFB--Missile Seeker Testing, Advanced Resistor Arrays (Wright Laboratory (Eglin) is one of the active participants in the MSSG project and is leading the resistor array (and support hardware) development work.)

NAWCWD, China Lake--Missile Seeker Testing, Advanced Infrared Projection Techniques, RF/IR Beam Combiners (NAWCWD is the lead and one of the active participants in the MSSG project and is leading the beam combiner development. An active development program to use especially coated optical fibers and laser array drivers to form low temperature infrared scenes is underway at NAWCWD. The use of these infrared emitting arrays as the heart of the infrared scene projection system may drive the cost down to less than one percent of the cost of that of the resistor arrays.)

TECOM, Redstone Arsenal--FLIR Testing, Large Resistor Arrays (TECOM is leading an effort to develop a large resistor array development for the testing of production and developmental FLIR systems.)

Naval Research Laboratory--Infrared Fiber Fluorescence (NRL is actively involved in the development of infrared fiber optics doped to fluoresce

in the mid band of the infrared. This fiber technology, together with that of the fiber bundle (NAWCWD above) and the micro laser technology (below) may provide the high temperature half of the solution to the infrared scene projection puzzle.)

Army Research--Micro-Laser Arrays (Arrays of micro lasers produced in microelectronics production facilities are the goal of the Army in supporting the development of arrays of micro lasers. These lasers could be used as sources for the infrared scene projection or as drivers for the infrared fibers being developed by NRL, or as drivers for the fiber arrays being developed by the NAWCWD.)

Air Force Electronic Warfare System (AFEWS) (AFEWS is actively involved in testing missile seekers and electronic warfare warning receivers.)

There are a number of other organizations that will benefit from these developmental works, such as those who are developing remote linking between test facilitites and analytical facilities. This advanced simulation test capability will help to make the output from these efforts more realistic and valid.

STATUS

Dynamic infrared scene projection systems are coming on line today. The blending of these infrared energies with RF energies will be happening within the year. Missile test facilities will be testing using these systems on a regular basis by the year 2000. Aircraft test facilities will be using these systems shortly thereafter.

CONCLUSIONS

The field of dynamic infrared scene projection has made huge strides in the past five years. Nevertheless, many shortfalls in speed, dynamic range, temperature range, and the like must be improved before we can test the broad span of capabilities of the missile seekers, FLIRs, and other infrared systems waiting to be tested.

Developmental efforts such as the kind described in this paper are continuing, and must continue so long as missile seeker/guidance systems continue their growth in capability and complexity.

These advanced RF/IR simulation test facilities must also meet the future challenges of VV&A.

Testing when using infrared scene projection in the 3 to 5 micron band brings to mind the name of a hot pepper catalogue, "Mo Hotta, Mo Betta."

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